Aerodynamic Modeling for the Ohio University UAV

For the
Quarterly Review of the NASA/FAA Joint University Program for Air Transportation Research

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U A V

Overview

- Brumby Specifications
- Basic Aerodynamics
- Instrumentation
- Future of the Brumby

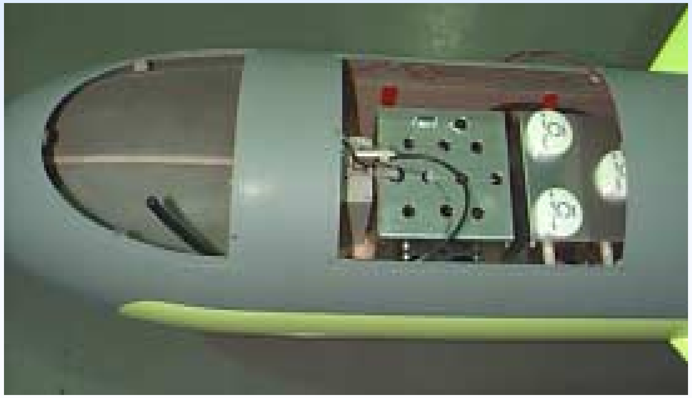
Configuration

- Delta wing aircraft
- Wing span (8.27 feet)
- Dual fins
- Fuselage length (6.46 feet)
- Pusher propeller configuration (7.2 hp)
- Fiberglass composite fuselage
- 10 channel radio control receiver

Performance Specifications

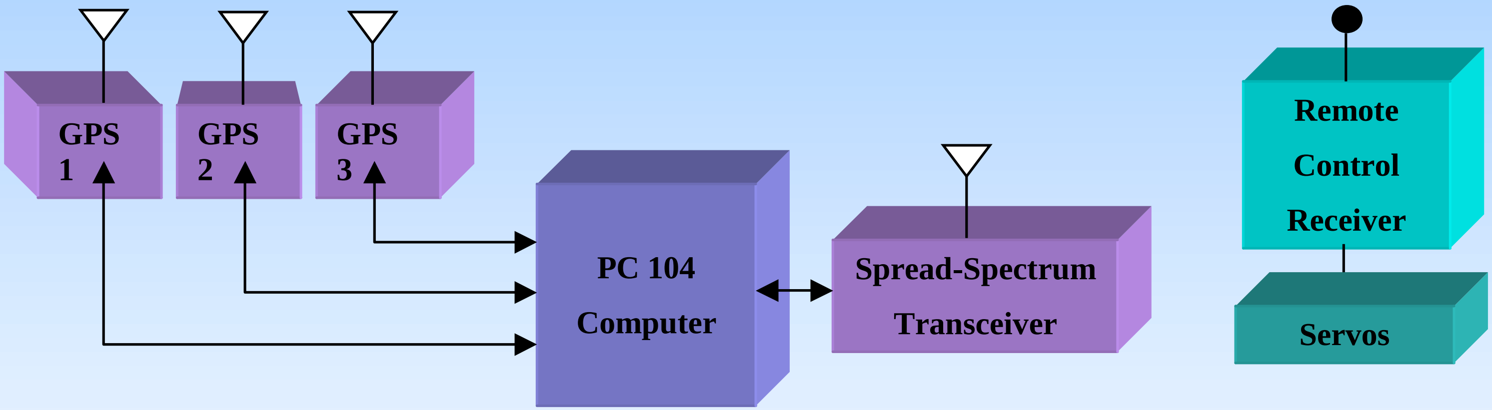
- **Maximum Speed:** **>100 knots**
- **Maximum Endurance:** **40 - 60 minutes**
- **Maximum Payload:** **<= 17.6 lb**
- **Payload Area:** **2 (300x220x200mm) sections**

Nose Cone Section

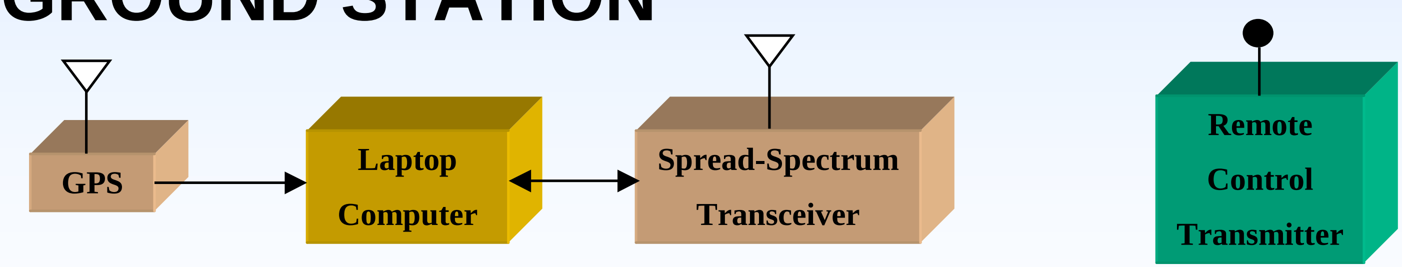


System Configuration

- **BRUMBY**



- **GROUND STATION**



Payload

- **Current Payload**
  - **PC 104 CPU with Pentium 166 MHz Processor**
    - **160 MB Solid State Hard Drive**
    - **QNX Operating System**
  - **3 Canadian Marconi AllStar GPS Receivers**
  - **FreeWave - 900 MHz Spread Spectrum Transceiver**
  - **NiCad Battery Packs**

Modeling

Moment of inertia computation:

$$\sum_i m_i \left(y_i^2 + z_i^2\right) = I_{xx} \qquad -\sum_i m_i z_i x_i = I_{xz} = I_{zx}$$

$$\sum_i m_i \left(z_i^2 + x_i^2\right) = I_{yy} \qquad -\sum_i m_i y_i x_i = I_{yx} = I_{xy}$$

$$\sum_i m_i \left(x_i^2 + y_i^2\right) = I_{zz} \qquad -\sum_i m_i z_i y_i = I_{zy} = I_{yz}$$

Modeling

Inertia matrix

$$I = \begin{bmatrix} I_{xx} & I_{xy} & I_{xz} \\ I_{yx} & I_{yy} & I_{yz} \\ I_{zx} & I_{zy} & I_{zz} \end{bmatrix}$$

Symmetry yields:

$$I = \begin{bmatrix} I_{xx} & 0 & I_{xz} \\ 0 & I_{yy} & 0 \\ I_{xz} & 0 & I_{zz} \end{bmatrix}$$

Modeling

Center of gravity computation:

$$X_{cg} = \frac{\sum_i m_i x_i}{\sum_i m_i} \qquad Y_{cg} = \frac{\sum_i m_i y_i}{\sum_i m_i}$$

$$Z_{cg} = \frac{\sum_i m_i z_i}{\sum_i m_i}$$

Governing Equations

- 3 Force Equations

$$\dot{U} = rV - qW - g_0 \sin\theta + \frac{F_x}{m}$$

$$\dot{V} = -rU + pW - g_0 \sin\varphi \cos\theta + \frac{F_y}{m}$$

$$\dot{W} = qU - pV - g_0 \cos\varphi \cos\theta \frac{F_z}{m}$$

- 3 Moment Equations

$$\dot{p} = (c_1 r + c_2 p)q + c_3 l + c_4 N$$

$$\dot{q} = c_5 pr - c_6 (p^2 - r^2) + c_7 M$$

$$\dot{r} = (c_8 p - c_2 r)q + c_4 l + c_9 N$$

Aerodynamic Coefficients (Force and Moment Equations)

- Drag: $D = \overline{q} * S * C_D$
- Lift: $L = \overline{q} * S * C_L$
- Side force: $Y = \overline{q} * S * C_Y$
- Rolling moment: $l = \overline{q} * S * b * C_l$
- Pitching moment: $M = \overline{q} * S * \overline{c} * C_M$
- Yawing moment: $N = \overline{q} * S * \overline{c} * C_N$

Aerodynamic Forces

$$\mathrm{F}_{\mathrm{B}} = \begin{bmatrix} F_x \\ F_y \\ F_z \end{bmatrix} = \begin{bmatrix} F_{x_A} \\ F_{y_A} \\ F_{z_A} \end{bmatrix} + \begin{bmatrix} F_{x_T} \\ F_{y_T} \\ F_{z_T} \end{bmatrix} = S * F_B$$

$$F_W = S * F_B = \begin{bmatrix} -D \\ Y \\ -L \end{bmatrix}$$

Aerodynamic Coefficients

- Symmetric modes.
  - C_D , C_L , $C_{m.}$
  - Angle-of-attack dominates in symmetric equations.
- Asymmetric modes.
  - C_Y , C_l, $C_{N.}$
  - Side-slip angle dominates in asymmetric equations.
- Whether 1st order terms suffice depends on amplitude of flight test maneuvers.

Aerodynamic Coefficients

$$C_D = C_{D_\alpha}(\alpha) + C_{D_q}(q) + C_{D_{\partial_e}}(\partial_e)$$

$$C_L = C_{L_\alpha}(\alpha) + C_{L_q}(q) + C_{L_{\partial_e}}(\partial_e)$$

$$C_M = C_{M_\alpha}(\alpha) + C_{M_q}(q) + C_{M_{\partial_e}}(\partial_e)$$

$$C_Y = C_{Y_\beta}(\beta) + C_{Y_\rho}(p) + C_{Y_r}(r) + C_{Y_{\partial_a}}(\partial_a) + C_{Y_{\partial_r}}(\partial_r)$$

$$C_l = C_{l_\beta}(\beta) + C_{l_\rho}(p) + C_{l_r}(r) + C_{l_{\partial_a}}(\partial_a) + C_{l_{\partial_r}}(\partial_r)$$

$$C_N = C_{N_\beta}(\beta) + C_{N_\rho}(p) + C_{N_r}(r) + C_{N_{\partial_a}}(\partial_a) + C_{N_{\partial_r}}(\partial_r)$$

Instrumentation

Required measurable variables

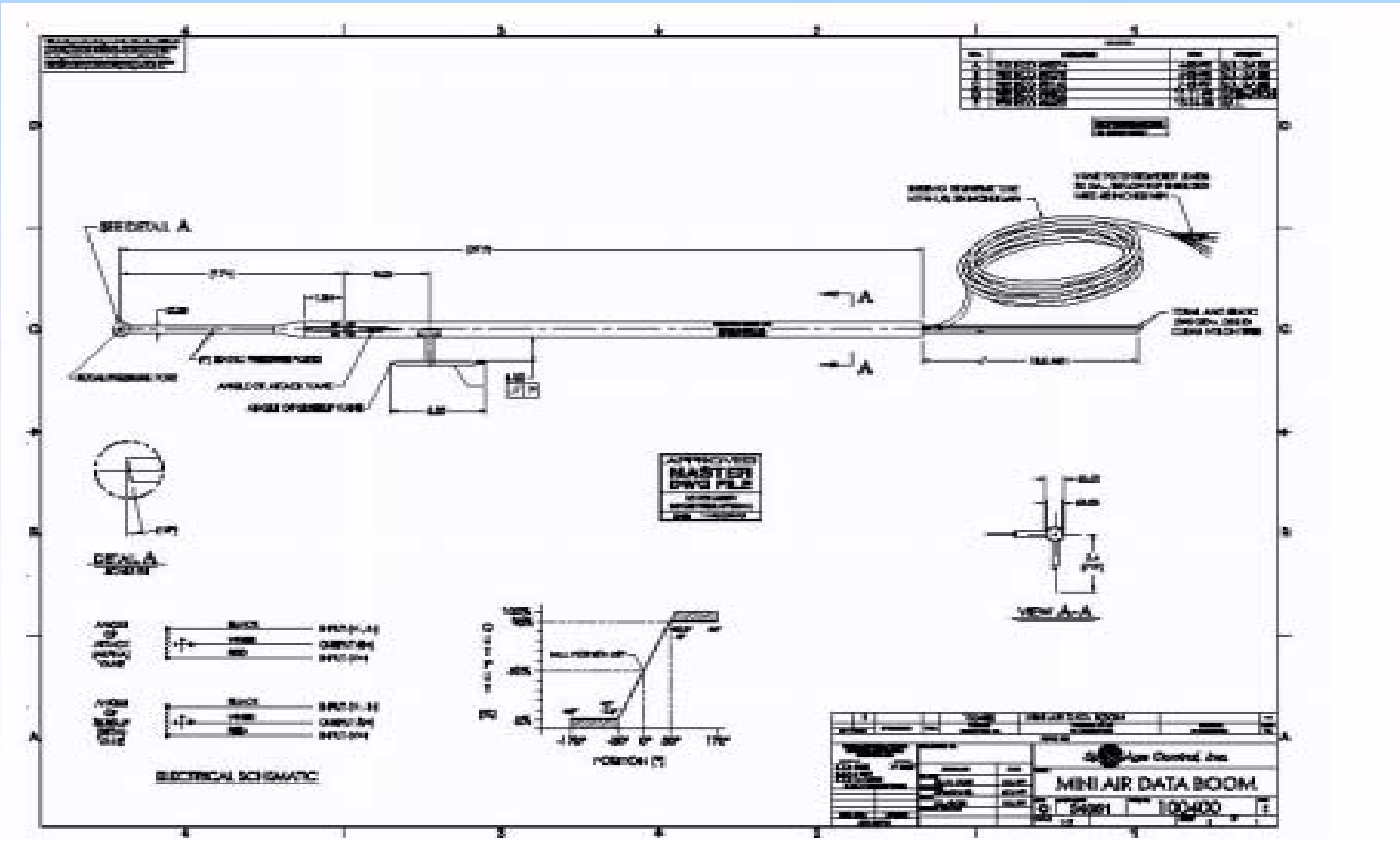
- Specific forces
  - Linear Accelerometers (IMU)
- Angular rates
  - Gyros (IMU)
- Angular accelerations
  - Time derivatives of rate measurements
- Propeller Thrust

Instrumentation

Required measurable variables (continued)

- Impact Pressure
  - Total pressure minus static pressure (Pitot Tube)
- Airspeed
  - Pitot Tube and Pressure Transducers
- Flow angles
  - Vane measurements
- Control surfaces
  - Servo output

Air Data Boom



Air Data Boom

- Required Electronics:
  - Total and static pressure
    - Nylon tubing
    - Pressure transducers
    - A/D converters
  - Angle of attack and sideslip
    - Potentiometer leads
    - A/D converter

Measurement of Forces

- Relationship between the specific force measurements to the total aerodynamic and propulsion forces acting on the aircraft:

$$F = m * f$$

  - F: Aerodynamic and Propulsion Forces
  - f: IMU Output
  - m: Total Aircraft Mass

Measurement of Forces

- Translation of the force sensor data to the aircraft center of gravity:

$$f_{x_{cg}} = f_{x_m} + (x_{cg} - x_m)(q^2 + r^2) - (y_{cg} - y_m)(pq - \dot{r}) - (z_{cg} - z_m)(pr + \dot{q})$$

$$f_{y_{cg}} = f_{y_m} + (y_{cg} - y_m)(r^2 + p^2) - (z_{cg} - z_m)(qr - \dot{p}) - (x_{cg} - x_m)(qp + \dot{r})$$

$$f_{z_{cg}} = f_{z_m} + (z_{cg} - z_m)(p^2 + q^2) - (x_{cg} - x_m)(rp - \dot{q}) - (y_{cg} - y_m)(rq + \dot{p})$$

Measurement of Forces

- Body to Flow reference frame transformation:

$$f_{x\ flow} = f_{x\ body} \cos\alpha \cos\beta + f_{y\ body} \sin\beta + f_{z\ body} \sin\alpha \cos\beta$$

$$f_{y\ flow} = -f_{x\ body} \cos\alpha \sin\beta + f_{y\ body} \cos\beta - f_{z\ body} \sin\alpha \cos\beta$$

$$f_{z\ flow} = -f_{x\ body} \sin\alpha + f_{z\ body} \cos\alpha$$

Measurement of Moments

- Total moment components:

$$L = \dot{p} I_{xx} + qr(I_{zz} - I_{yy}) - (pq + \dot{r}) I_{xz} + I_p \dot{\omega}_p$$

$$M = \dot{q} I_{yy} + rp(I_{xx} - I_{zz}) - (p^2 + r^2) I_{xz} + I_p \omega_p r$$

$$N = \dot{r} I_{zz} + pq(I_{yy} - I_{xx}) - (qr + \dot{p}) I_{xz} - I_p \omega_p q$$

Future of the Brumby

- Analyze inertia properties (November 2001)
- Development and testing of flight data instrumentation. (January 2002)
- Development of analysis software for post-flight parameter identification. (January 2002)
- Flight Test (Spring 2002)
- Brumby Model (Summer 2002)

References

- **Laban, M.** (1994). *On-Line Aircraft Aerodynamic Model Identification*. PhD. Dissertation Delft University of Technology.

- **Stevens, B.L., and Lewis, F.L.** (1992). *Aircraft Control and Simulation*. John Wiley & Sons, Inc.